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C. Lowe and M.G. Mihalynuk

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Authors' addresses

C. Lowe *(clowe@nrcan.gc.ca)*
Geological Survey of Canada
9860 West Saanich Road
Sidney, British Columbia V8L 4B2

M.G. Mihalynuk *(Mitch.Mihalynuk@gems5.gov.bc.ca)*
British Columbia Geological Survey Branch
1810 Blanshard Street
Victoria, British Columbia V8W 9N3

Overview of the Atlin Integrated Geoscience Project, northwestern British Columbia[1]

C. Lowe and M.G. Mihalynuk
GSC Pacific, Sidney

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Abstract: The Atlin Integrated Geoscience Project is a three-year initiative designed to advance our understanding of the geological evolution and mineral-resource potential of the northern Cache Creek Terrane, principally through the application of geophysical and geological mapping surveys within the Atlin map area. The project was launched in 2000, with the collection of aeromagnetic data funded by the federal government's Targeted Geoscience Initiative. During 2001, matching funding by the British Columbia Geological Survey Branch permitted systematic bedrock mapping at a scale of 1:50 000 in the southern project area, and follow-up ground-based, magnetic and reconnaissance geological surveys of postaccretionary plutonic bodies. This work was conducted in partnership with geoscientists from Canadian and European universities. The geological mapping components were enhanced by geochemical, isotopic, and geo- and biogeochronological data. Four thesis projects will evaluate sequence stratigraphy, volcanic environments and petrogenesis, origin of ultramafic bodies, and tectonic evolution of serpentinite mélange belts.

Résumé : Le projet géoscientifique intégré d'Atlin a été conçu afin d'approfondir notre compréhension de l'évolution géologique et du potentiel minéral de la partie nord du terrane de Cache Creek. Échelonné sur une période de trois ans, ce projet a recours principalement à des levés géophysiques et des travaux de cartographie géologique dans la région cartographique d'Atlin. Le projet a été lancé en l'an 2000 par la collecte de données aéromagnétiques dans le cadre d'un levé financé par l'Initiative géoscientifique ciblée du gouvernement fédéral. En 2001, un financement de contrepartie de la Geological Survey Branch de la Colombie-Britannique a permis de réaliser la cartographie systématique du substratum rocheux à une échelle de 1/50 000 dans la région sud du projet et d'effectuer des études de suivi des massifs plutoniques postaccrétionnaires à l'aide de levés magnétiques au sol et de levés géologiques de reconnaissance. Cette étude est le fruit d'un partenariat entre des géoscientifiques d'universités canadiennes et européennes. Les composantes de cartographie géologique ont été améliorées grâce à l'apport de données géochimiques, isotopiques, géochronologiques et biogéochronologiques. Quatre projets de cycles supérieurs évalueront la stratigraphie séquentielle, les environnements et la pétrogenèse volcaniques, l'origine des massifs de roches ultramafiques et l'évolution tectonique des bandes de mélange à serpentinite.

[1] Contribution to the Targeted Geoscience Initiative

INTRODUCTION

The Atlin Integrated Geoscience Project area, encompasses map area NTS 104 N in northwestern British Columbia (Fig. 1). Placer gold exploration and mining have been a mainstay of the economy of the Atlin region for much of the last century; however, despite an abundance of prospective lithologies and geological environments, the region remains underexplored for base metals and other precious mineral deposits. To help address this issue, scientists from the Geological Survey of Canada (GSC), the British Columbia Geological Survey Branch, and Canadian and European universities have joined expertise to investigate the potential for lode gold, volcanogenic massive sulphide (VMS), and other mineral deposits in this region under the auspices of the GSC's Targeted Geoscience Initiative. Allied objectives of the Atlin Integrated Geoscience Project are: 1) to advance our understanding of the geological evolution of the northern Cache Creek Terrane by establishing its stratigraphy and investigating the timing and processes involved in the emplacement of the terrane; and 2) to investigate the nature, age(s), and petrology of postaccretionary plutonic rocks within the project area.

During the first year of the project (2000–2001) provincial 1:20 000-scale Terrain and Resource Information Management (TRIM) elevation data were acquired and manipulated to produce a digital elevation model (DEM). The digital elevation model was used to design a survey plan for acquisition of high-resolution aeromagnetic data (*see* Lowe and Anderson, 2002), as well as to investigate the extent to which topography reflects the underlying bedrock and surficial geology. Subsequently, approximately 30 400 line kilometres of aeromagnetic data were acquired covering the entire project area. A colour-enhanced surficial geology map of the Atlin placer district was produced and existing geoscience information was recompiled, based largely on an extensive compilation effort in the mid-1990s (Mihalynuk et al., 1996), but including additional sources such as unpublished 1:25 000-scale mapping by Jim Monger (GSC).

In 2001, geological mapping of map areas NTS 104 N/1, 2; reconnaissance mapping of plutonic rocks in NTS 104 N/5, 6, and 7; and ground follow-up investigations of selected magnetic anomalies were undertaken during the summer field season. In the autumn and winter of 2001, data sets will be integrated and interpreted. Aeromagnetic data will be modelled and a geological map of NTS 104 N/1 will be produced for release in early 2002. In the last half of 2002, project plans call for completion of mapping of NTS 104 N/2, 3, and timely publication as British Columbia Geological Survey Branch open file maps in early 2003. Reconnaissance and detailed mapping, petrographic and geochemical analysis, and isotopic age dating and characterization of plutonic rocks will lead to timely syntheses of the data published in external journals.

This paper outlines preliminary findings of all project components. No analytical data are reported here, although references are included to more in-depth summaries in this volume and '*Geological Fieldwork*' papers of the British Columbia Geological Survey Branch. More comprehensive reports and maps are scheduled for year three (2002).

Figure 1. *Location of the Atlin Integrated Geoscience Project in northwestern British Columbia. The project is a component of the federal government's Targeted Geoscience Initiative.*

MAGNETIC STUDIES

Between September 2000 and March 2001, SIAL Geosciences Inc., under contract to the GSC, acquired 30 375 line kilometres of high-resolution aeromagnetic data in the Atlin project area. Flight lines, which were oriented northeasterly, perpendicular to the geological strike, were spaced 500 m apart and flown at a minimum terrain clearance of 200 m. Control lines were flown at a 3 km interval. The GSC's Aeromagnetic Surveys Group (Regis Dumont, Maurice Coyle, Josée Potvin) monitored data quality throughout the acquisition and processing phases and produced a series of sixteen 1:50 000 GSC Open File maps and digital data products for public release on October 1, 2001 (Dumont et al., 2001a, b, c, d, e, f, g, h, i, j, k, l, m, o, p).

Carmel Lowe and Bob Anderson (GSC Pacific) undertook ground follow-up investigations of selected anomalies during the 2001 field season and conducted magnetic susceptibility measurements on more than 200 bedrock samples and outcrops to assist with interpretations of the airborne data and to develop models that constrain the geometry of specific rock units and structures at depth.

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The magnetic field observed over the project area is rich in magnetic anomalies. Individual anomalies accurately outline the mapped extent of some bedrock units. Anomaly trends and magnetic lineaments delineate several mapped structures; however, the value of the magnetic data rests not only in this confirmation of the known geology. New insights into the bedrock geology and exploration potential of the region are provided by the numerous additional anomalies and lineaments whose sources are not reflected in published bedrock maps. The following points highlight some important features in the new data set (*see* Lowe and Anderson (2002) for more details).

Prominent, northwest-trending, magnetic lineaments correspond with the surface trace of several mapped faults including the Nahlin, Llewellyn, and Teslin faults. A series of similarly oriented lineaments is clearly imaged over the eastern portion of the Surprise Lake batholith and adjacent aureole, but no faults are mapped in these regions.

Three, regionally extensive (>30 km long) and several shorter east- to east-northeast-trending magnetic lineaments are imaged. To date, structures of this orientation have not been recognized in the Atlin project area, although east-northeast-trending faults have been mapped in the Tagish map area farther to the west (Mihalynuk, 1999). The lineaments bound several intrusive bodies along their southern margins, suggesting a possible correlation between the magnetically delineated structures and the emplacement of the plutons.

The most intense magnetic anomalies observed within the entire project area correspond with exposures of ultramafic rocks. The anomaly associated with the Nahlin ultramafic body in the southern project area indicates that the body may be significantly more extensive in the near subsurface than surface geological mapping has hitherto indicated.

Major differences in the magnetic response of postaccretionary plutonic rocks are recognized: the Fourth of July, Coconino, and Slaughter House intrusions typically correlate with strong, positive magnetic anomalies; the Surprise Lake batholith is weakly magnetic; the magnetic fields observed over the Llangorse, Mount McMaster, and Chichoida plutons are heterogeneous with distinct zones of positive and negative magnetic anomalies observed within each body. The magnetic fields observed over the Mount McMaster and Llangorse plutons, together with in situ magnetic susceptibility measurements, point to subtle lithological and/or composition changes within these bodies which are not recognized in field mapping.

Several small (<5 km), suboval, positive and negative magnetic anomalies punctuate the smooth magnetic field that characterizes regions underlain by the Kedahda assemblage (dominated by chert, argillite, siltstone, and limestone) in the central part of the project area. At least two of these anomalies correlate with reported outcrops and subcrops of porphyry intrusions and with known mineralization.

BEDROCK MAPPING

Bedrock mapping at a 1:50 000 scale was conducted in the Nakina transect, which encompasses map areas NTS 104N/1, 2, and 3 (Fig. 2). Access to the area is by helicopter, floatplane, horseback, or foot travel; no roads service the area. Because of the short field season the project team relied upon helicopters as the most efficient mode of travel. Charter helicopter service is available from Discovery Helicopters based in Atlin.

The Nakina transect was selected as it was anticipated to offer the best exposures and most complete stratigraphy of the entire Cache Creek Terrane (Monger, 1975). Additionally, its mineral resources are largely untested despite favourable geology and numerous multi-element regional geochemical survey stream sediment anomalies (Jackaman, 2000). The mapping builds on previous work by Aitken (1959) and Monger (1975). Mitch Mihalynuk (British Columbia Geological Survey Branch), Steve Johnston (University of Victoria

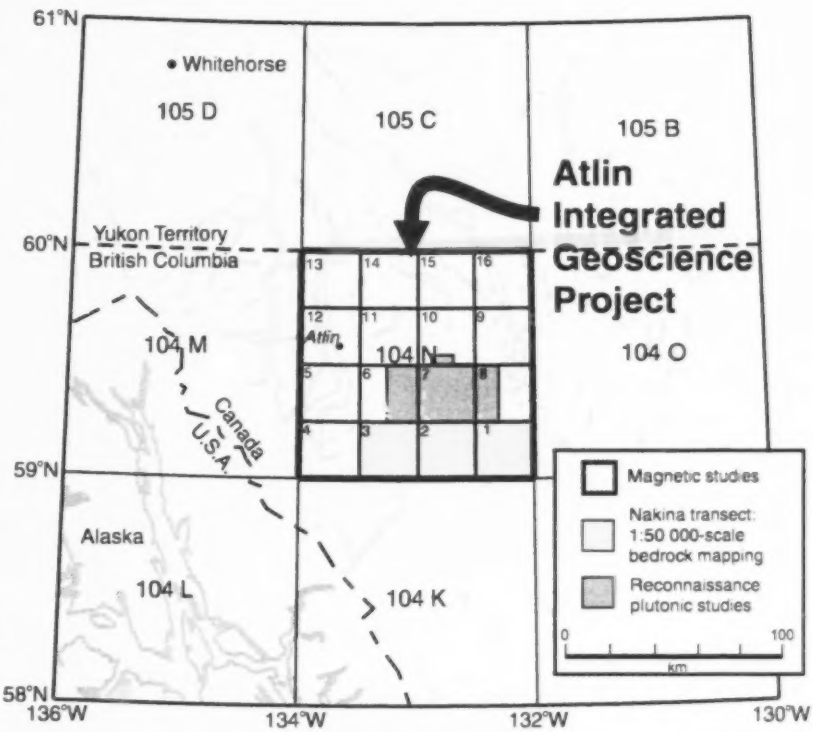

Figure 2. *Detailed location map showing the areas investigated in the bedrock mapping and reconnaissance plutonic studies.*

(UVic)), and Fabrice Cordey (Université Claude Bernard, Lyon, France) were responsible for the delivery of this project component. Despite generally inclement weather, exceptional geological mapping by students Fionnuala Devine (UBC), Joe English (UVic), Kyle Larson (UVic), and Yann Merran (Université Claude Bernard, Lyon, France) led to completion of map coverage as scheduled (NTS map area NTS 104 N/1, plus most of NTS 104 N/2) during July and August. Detailed sampling and stratigraphic studies augmented mapping. Samples were collected for micro- and macropaleontology, lithogeochemistry, and isotope geochronology. Stratigraphic studies concentrated on sections of interlayered volcanic and carbonate rocks. Mineralized outcrops were sampled to determine base-metal and precious-metal content. The following are the main highlights of the Nakina transect mapping of 2001.

Quartz-phyric felsic volcanic rocks with potential for volcanogenic massive sulphide deposits were discovered in central NTS104 N/2. These felsic volcanic rocks appear intercalated with chert that contains radiolaria of possible Middle Triassic age. Their extent is currently not well defined, but regional geochemical survey data from creeks that drain the area are elevated in copper (80 ppm), lead (6 ppm), molybdenum (6 ppm), zinc (122 ppm), mercury (230 ppm), and gold (10 ppb) (samples 9695, 9700, 9895; Jackaman, 2000).

A fine-grained tuffite unit containing exhalative magnetite layers with elevated barium was discovered in northwestern NTS 104 N/2. Black magnetite-rich rock comprised up to 50% of cross-sections at least 5 m thick (16% Fe, 900–1200 ppm Ba over 5.3 m). Mineralization occurs across a width of 25 m and can be traced for more than 700 m along strike. Regional geochemical survey results are unavailable for the drainage basin directly underlying the exhalite, but values from the creeks draining areas, underlain in part, by correlated tuffite are elevated in Au (41 ppb), As (31 ppm), Cu (64 ppm), and Zn (118 ppm) (samples 9215, 9224; Jackaman, 2000).

The tuffite occurs within several thrust sheets that comprise part of a previously unrecognized fold and thrust belt. This fold and thrust belt is particularly well developed in an area south of Nakina River where distinctive and laterally persistent units are tightly folded, truncated by thrusts, and repeated. A regional décollement that places Permo-Carboniferous fusulinid packstones above Middle Triassic chert can be traced for at least 20 km along strike (Fig. 3).

Quartz-rich wacke is observed at several localities in lower Horsefeed Creek, most commonly within strata that are tentatively interpreted as relics of an accretionary prism (Fig. 4). In at least one case, the quartz can be shown to have a volcanic source.

In northern NTS 104 N/1 coarse augite porphyry breccia with blocks up to 1 m in diameter comprises a laterally extensive unit up to 250 m thick. It is monomict and interpreted as a proximal volcanic-arc deposit, although the volcanic centre has yet to be mapped. Preliminary observations suggest that the unit rests with angular discordance on chert and is intercalated with overlying limestone.

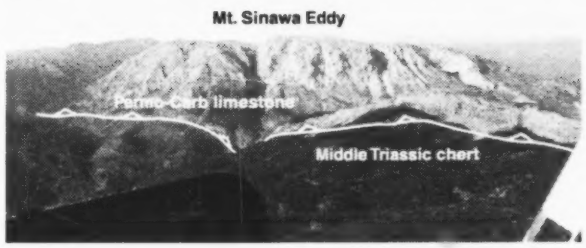

Figure 3. Regional thrust that places Permo-Carboniferous (Permo-Carb) limestone on Middle Triassic chert. Photograph by M.G. Mihalynuk.

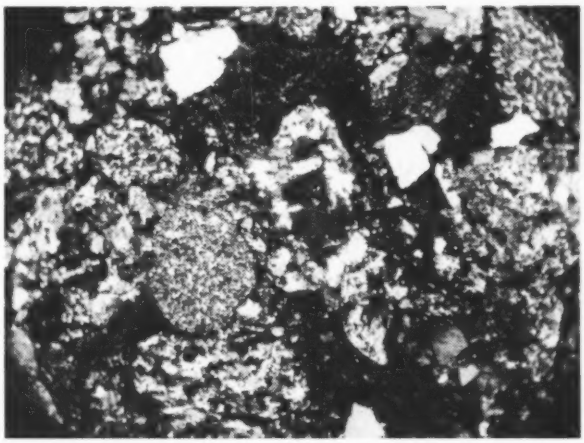

***Figure 4.** Quartz grains of volcanic, plutonic, and metamorphic sources occur together with chert and carbonate grains in this sample of relatively clean lithic sandstone within wacke from the eastern part of the Nakina mapping transect. Photograph by F. Devine.*

Extensive tracts of serpentinite mélange were not previously mapped within the south-central map area. Blocks of mafic volcanic rocks up to 2.5 km in plan section are enveloped by scaly serpentinite. Smaller knockers are dominated by basalt and diabase, but also include chert, trondjhemite, and rare limestone. Knockers are commonly cigar-shaped, with long axes plunging steeply (Fig. 5).

At two localities to the south of Dry Lake, relatively competent blocks of limestone pierce mélange belts. At another locality in lower Horsefeed Creek, a complex of structurally interleaved wacke and chert panels (possible accretionary prism) is truncated by a coherent block of carbonate. These appear to be small-scale examples of indenter tectonics.

Figure 5. *Resistant, subvertical rod-shaped knockers of mafic volcanic rocks, diabase, gabbro, and chert, sticking out of a mountainside of scaly serpentinite (western part of NTS 104 N/1). Photograph by M.G. Mihalynuk.*

In the lower Horsefeed Creek region one coherent carbonate block is dominated by fusulinid packstone and is rich in ammonites. Fusulinids in these rocks range up to more than 1 cm in diameter, and are probably large Tethyan species. Tethyan ammonites are relatively rare within the Cordillera.

A synorogenic basin was mapped atop basalt of the Cache Creek oceanic crustal section in southwestern NTS 104 N/2. Coarse clastic rocks within this basin are encompassed by Aitken's (1959) (?)Triassic unit 10. An excellent basal conglomerate is developed which is dominated by basalt clasts. It rapidly gives way to quartz and chert granule-rich sandstone and conglomerate. Exotic boulders of porphyritic intrusions are abundant, but have no known source within the local Cache Creek section. The conglomerate also contains angular intraclasts up to several metres in diameter as well as a carbonate layer several metres thick.

More detail and discussion of these highlights are presented in Mihalynuk et al. (in press b) and English et al. (in press).

PLUTONIC STUDIES

Bob Anderson and Carmel Lowe (GSC Pacific) conducted a six-day reconnaissance mapping and sampling program focused on the Mount McMaster and Llangorse plutons and their adjacent thermal aureoles (Fig. 2). Favourable map transects were selected based on previous mapping by Aitken (1959) and the new aeromagnetic data. The Mount McMaster and Llangorse plutons are distinguished by grain size, composition, and mineralogy of constituent felsic and mafic phases (Fig. 6). Correlations among aeromagnetic anomalies, magnetic susceptibility data, and rock composition varied from generally strong to locally poor, requiring further mineralogical investigations. Samples of all distinct phases were collected for ongoing U-Pb and Ar-Ar isotopic dating, petrographical, and mineralogical analysis, and geochemical characterization to help constrain interpretations of their genesis and age(s) of mineralization.

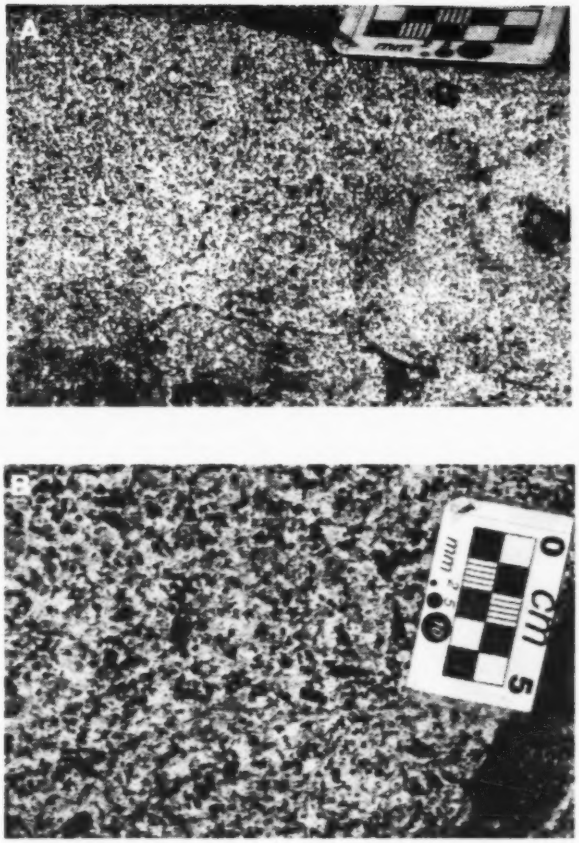

Figure 6. A) *The fine- to medium-grain size and equigranular texture visible in this photograph are typical of the biotite granite phase at core of the Mount McMaster pluton.* ***B)*** *The prismatic hornblende and seriate texture visible in this photograph are typical of the extensive biotite-hornblende quartz monzogranite underlying the central Llangorse Mountain massif. Dark grey grains are quartz and white grains are feldspar. Photographs by R.G. Anderson.*

Samples of two porphyry intrusions exposed to the north of the Llangorse pluton were also acquired. Each of the porphyry intrusions has associated base-metal mineralization according to the provincial MINFILE database. Gossans and hydrothermally altered rocks around the porphyry intrusions generate distinct, suboval, magnetic anomalies.

Further reconnaissance and detailed mapping of intrusions within the Atlin map area, including the Surprise Lake batholith, are planned to resume during the 2002 field season. Future work will help refine hypotheses concerning the origin, timing, and mode of emplacement of the intrusions and contribute to the understanding of the anomalously high gold values known from regional geochemical survey samples from streams draining the plutons and their aureoles. Was some of the gold which accumulated in the Atlin camp placers eroded from lodes in or near these plutonic bodies?

AGE DATING

Geological age constraints within the Atlin project area are relatively sparse. Recent summaries of isotopic age data cover much of the area (Mihalynuk, 1999; Mihalynuk et al., in press a). Monger (1975) provided the most complete synopsis of Paleozoic macrofossils, whereas Johannson (1996) tabulated Mesozoic fossil age data, mainly from ammonite collections. Microfossil age data, on the other hand, is scattered through many publications, or remains unpublished. Prior to the 2001 field season, a database of existing conodont collections from rocks within the project area was compiled by Mike Orchard (GSC Pacific). In total, 67 conodont and/or ichthyolith collections were known from the Atlin map area as a result of spot sampling during the period 1976–1999. Of these, 37 collections are diagnostic as to age. Most are from the Cache Creek Group and include records of the Early Carboniferous (late Visean–Serpukhovian, 7 collections); Late Carboniferous (Bashkirian–Moscovian, 8 collections); Permian (13 collections); and Late Triassic (Late Carnian, 3 collections — 1 referred to Stuhini Group; Early Norian, 2 collections; Middle Norian–Rhaetian, 4 collections from Sinwa Limestone or from clasts in the Inklin Formation). The most notable fossil record amongst these is that of *Lochriea nodosa*, a late Mississippian conodont taxon that occurs nowhere else in North America.

Broad tracts of siliceous argillite and ribbon chert that are at very low metamorphic grade within the Atlin map area provide good opportunities for the recovery of radiolaria. Fabrice Cordey (Université Claude Bernard, Lyon, France) has undertaken studies of radiolaria in the Atlin area since 1989. He joined the bedrock team for the second half of the field season and established a radiolarian extraction facility at the base camp in Atlin and undertook processing and preliminary analysis of 30 radiolarian-bearing chert and argillite localities. In addition to field mapping and sampling, Cordey identified radiolaria spanning Early Permian to Middle Triassic age. Ongoing micropaleontological investigations by Fabrice Cordey and Mike Orchard will continue to refine the stratigraphy of the northern Cache Creek Terrane.

Bedrock mapping will be further assisted through isotope geochronological investigations by Mike Villeneuve (GSC) and Fionnuala Devine (UBC). Villeneuve collected samples for U-Pb zircon age determinations from quartz diorite and trondjhemite of the oceanic crustal section, as well as samples for dating of detrital components within two quartz-rich clastic units. Samples were also taken for $^{40}Ar/^{39}Ar$ analysis of macrocrystic hornblende within plagiogranite segregations of the same section. The U-Pb and $^{40}Ar/^{39}Ar$ analysis of Cretaceous and Jurassic plutonic rocks will provide information on the temporal evolution of plutonic suites with metallogenic potential. Devine focused on collection of felsic intrusive knockers within serpentinite mélange belts near Nakina Lake.

GEOGRAPHICAL INFORMATION SYSTEM PRODUCTS

Robert Kung and Carmel Lowe (GSC Pacific) used 25 m digital elevation data acquired from the provincial Terrain and Resource Information Management database to generate a shaded-relief digital elevation model for the project area. The model provides abundant evidence of the impact of glaciation and bedrock geology on topography, and as such, is a useful tool for a variety of industry and academic geoscientists working in this area. The small scale of the model (1:250 000) allows large landforms, not commonly imaged on large-scale aerial photographs, to be readily distinguished. The digital elevation model was also used in the design of a flight plan to facilitate the acquisition of high-resolution aeromagnetic data over the rugged terrain that characterizes this project area (*see* Lowe and Anderson, 2002). Robert Kung (GSC), Victor Levson (BCGS), and Carmel Lowe (GSC) digitized and generated a colour-enhanced surficial geology map of the Atlin placer mining district.

Mitch Mihalynuk (BCGS) together with Joe English (UVic M.Sc. candidate) are currently working on a digital geological map of NTS 104N/1, 2 with topology and related spatial database. Robert Kung will complete final cartography and rendering at the GSC.

STUDENT TRAINING

Three geology theses are supported by the Atlin Integrated Geoscience Project: Yann Merran (Université Claude Bernard) is undertaking a Masters thesis on sequence stratigraphy in the Cache Creek Terrane. Joe English (UVic) is investigating volcanic environments and petrogenesis in the Cache Creek Terrane, also for a Masters thesis. Fionnuala Devine (UBC) is studying the tectonic evolution of serpentinite mélange belts within the terrane for a Bachelor's thesis. In addition, Greg Shellnut (UVic) is receiving partial support for his doctoral thesis on the origin of ultramafic bodies in the Cordillera.

OUTREACH ACTIVITIES

Outreach activities are an important component of the Atlin Integrated Geoscience Project. To date, such activities have included:

1. the development of a project web site (URL: http://www.pgc.nrcan.gc.ca/atlintgi) which outlines all aspects of the project, provides timely updates on new data and project developments and details upcoming project activities;
2. the delivery of a public geoscience lecture series at the Globe Theatre in Atlin during the 2001 field season. Presentations covered many aspects of the geology and tectonic evolution of the Atlin area, its mining history and mineral potential, and the utility of magnetic data in mineral exploration; and

3. the development of an Atlin Geoscape poster headed up by Bob Anderson and Nichola Hastings (GSC) which will provide a synopsis of geoscience issues (including the development of landforms, placer mining, the geological history of the area, and the utility of the new aeromagnetic data) in a format accessible to a broad audience of interested lay public.

ACKNOWLEDGMENTS

All project participants contributed to the success of this year's project and to this overview. Project funding comes directly through the GSC's Targeted Geoscience Initiative and the British Columbia Geological Survey Branch. In addition, in-kind support from the many universities listed throughout the text is appreciated. Jim Monger (GSC emeritus) kindly gave us a pictorial introduction to the Nakina area together with his original field map data. All field parties extend warm thanks to Norm Graham (Discovery Helicopters) for his expert flying skills and tireless energy. P. Jane Wynne (GSC) and Ewald Lemke (Atlin Realty) enthusiastically promoted the summertime lecture series at the Globe Theatre.

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